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Article

Biochar from sugarcane apexes in the initial growth of cucumber

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Abstract

One of the main uses of biochar is as a soil improver; however, there are few studies on its use as a substrate with the aim of reducing the use of commercial peat moss. The effect of the physical properties of biochar from sugarcane apexes on the growth of 'Thunderbird' cucumber seedlings was evaluated. The treatments were mixtures of Bsca and peat moss (P): 0/100, 20/80, 40/60, 60/40, 80/20, and 100/0 v/v. The sowing was carried out in a greenhouse of the Autonomous University of the State of Morelos and physical properties of the substrates and growth variables in cucumber seedlings were evaluated with a completely randomized experimental design and randomized blocks, respectively. Peat moss produced the highest seedling growth; on the other hand, the proportions 20Bsca:80P and 40Bsca:60P allowed a good root development by presenting a fresh root weight, with 607.83 and 664.83 mg; whereas in root dry weight, they had 39.83 and 37.33 mg, respectively, values similar to those obtained in peat, these results were related to the physical properties of these mixtures, where the particle size determined the pore space available for water and air. Biochar from sugarcane apexes can be added up to 40% to commercial peat moss without altering the physical properties of an ideal substrate; likewise, mixtures of 20 and 40% biochar with peat moss allow the growth of cucumber seedling roots similar to those obtained in commercial peat moss.

Keywords:

Cucumis sativus L., biochar, physical properties, substrate.

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Introduction

Cucumber (*Cucumis sativus* L.) belongs to the family Cucurbitaceae and is one of the vegetables whose production is exported in more than 90% to the United States of America, which generates a high economic spillover in the producing states, which is derived from the labor (150 days of work ha^{-1}) that is required for crop management (Rebollar-Rebollar *et al*., 2022). In 2023, 4 651.2 ha were planted in Mexico under protected agriculture (greenhouse, shade cloth, and high tunnel), with a production value of $4 845 188 340.00.

This crop is planted in 22 states of the Mexican Republic, with an average yield of 111.59 t ha^{-1} (SIAP, 2024). Biochar is a porous-solid material that is obtained by processes of pyrolysis, hydrothermal carbonization, microwave carbonization, gasification, and torrefaction with high carbon content (Ortega-Ramírez and Olaya-Pulido, 2022; Ravindiran *et al*., 2024); the raw material used for its production is mainly vegetable waste, forestry waste, industrial sludge, and municipal waste; such as garden pruning, land clearing, wood pallets and packaging (Adeyemi and Idowuo, 2017; Velázquez-Maldonado *et al*., 2019).

The physical and chemical characteristics of biochar are determined by factors such as the composition of the raw material, heating range, temperature and pressure of the reactor, and the use of catalysts according to the technique used in its production (Escalante-Rebolledo *et al*., 2016; Arévalo-Ortega *et al*., 2023).

The best-known use of biochar is as a soil improver; its addition can influence its physical properties, such as texture, structure, pore size distribution, total porosity, aeration porosity, moisture retention porosity, and bulk density, as well as to favor the development of microorganisms, positively influence by increasing the cation exchange capacity and nutrient retention, improve pH balance, and provide organic matter (Orozco-Gutiérrez *et al*., 2021; Arévalo-Ortega *et al*., 2023).

On the other hand, the production of seedlings in trays is one of the most important stages in the production of horticultural crops since it reduces the loss of seedlings and healthy, vigorous plants with uniform growth are obtained, which helps to generate optimal yields. In this context, Villegas-Torres *et al*. (2017); Castro-Garibay *et al*. (2020) mention that peat moss or special mixtures are the most commonly used organic substrates for seed germination due to their physical and chemical properties that favor the germination process, growth, and development of seedlings; nevertheless, commercial germination mixes, such as Sunshine mix 3, have high costs because it is a product that is imported from Canada.

In this sense, the use of biochar may be an option to reduce the use of commercial peat moss as a substrate because it has shown favorable results in vegetable production depending on the origin and processing of the biochar and the plant species (Huang and Gu, 2019; Guo, 2020); therefore, it is necessary to evaluate the use of agricultural residues for the production of vegetable seedlings that allow partial replacement of commercial peat moss. Therefore, the present research aimed to evaluate the effect of the physical properties of the biochar from sugarcane apexes on the growth of ‘Thunderbird’ cucumber seedlings.

Materials and methods

The research was divided into two stages: the first was conducted in April 2019 and consisted of the physical characterization of peat moss (P), biochar from sugarcane apexes (Bsca), and mixtures of both materials; in addition, the nutritional concentration of the peat moss and biochar was determined. This stage was developed in the Soil Laboratory of the Academic Division of Agricultural Sciences of the Juárez Autonomous University of Tabasco (DACA-UJAT), for its acronym in Spanish. The second stage consisted of evaluating peat moss, biochar and mixtures of both materials in the growth of seedlings of cucumber (*Cucumis sativus* L.) ‘Thunderbird’ and was carried out in the Experimental Field of the Faculty of Agricultural Sciences of the Autonomous University of the State of Morelos (FCA-UAEM), for its acronym in Spanish.

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Determination of physical and chemical properties

Six treatments were evaluated to characterize the physical properties; the commercial mixture Sunshine mix 3 was used as a control (T1:P). On the other hand, biochar was made from sugarcane apexes with the hydrothermal carbonization (HTC) technique at 200 °C with the addition of 10% citric acid as a catalyst using the methodology described by Velázquez-Maldonado *et al*. (2019) (T2: BSCA), and both materials were used to make mixtures v/v in the following proportions: 20Bsca:80P (T3), 40Bsca:60P (T4), 60Bsca:40P (T5), and 80Bsca:20P (T6).

Granulometry. A composite sample of 800 cm^3 was used and sieved with an electric sieve with sieves (Mont-Inox and Ficsa de CV) numbers 8, 10, 12, 16, 20, and 50 (2.38, 1.68, 1.41, 1.15, 0.86, and 0.24 mm, respectively) with a stirring time of three min, the content of the mixtures of each sieve was weighed, and the percentage was calculated by particle size.

Bulk density (BD). Styrofoam permeameters with a capacity of 232 ml were used. The mixtures were saturated with running water for 24 h; then they were placed on the permeameters and dried at 65 °C to a constant weight. The bulk density (BD) was calculated with the formula: BD= weight of the dry substrate (g)/total volume (cm^3). Total porosity (TP), aeration porosity (AP), and moisture retention porosity (MRP) were determined with the procedure described by Landis *et al*. (1990).

Nutritional concentration. The following was determined for the biochar from sugarcane apexes and for the commercial peat moss: nitrogen (N) with the micro Kjeldahl method, phosphorus (P) with vanadate-molybdate yellow. K, Ca, and Na by flammometry and Mg by spectrophotometry, according to the Official Mexican Standard Proy-Nom-021-Recnat-2000 (DOF, 2000). In the first stage, a completely randomized design with three replications was used to determine the physical (BD, TP, AP, and MRP) and chemical properties of the substrate mixtures evaluated.

Evaluation of mixtures of biochar and peat moss in the greenhouse

This stage was developed in a tunnel-type greenhouse of the FCA-UAEM. The average temperature and relative humidity of the greenhouse were 28.5°C and 65%, respectively, which were recorded with a datalogger (U12, Hobo®). 'Thunderbird' (Seminis®) cucumber seeds and 200-cavity polystyrene germination trays with a capacity of 20.5 ml per cavity were used. From sowing, June 25, 2019, and during the growth of the seedlings, they were irrigated manually with purified water by reverse osmosis.

At 23 days after sowing, July 18, 2019, the following variables were measured: stem length, from the base of the stem to the apex with a conventional ruler graduated in cm; fresh weight of aerial and root biomass, weighing each organ separately on an Ohaus® scale with an approximation of 0.01 g; dry weight of aerial and root biomass by drying fresh stem, leaf, and root biomass in a Luzeren® Pro1002498 circulating air oven at 70 °C to constant weight.

Leaf area was measured with a Li-Cor® LI-3100C leaf area meter, Lincoln, Nebraska, USA, expressed in cm^2. The second stage used an experimental randomized block design with six replications and 10 seedlings as the experimental unit.

Statistical analysis

To ensure normality, the data expressed as a percentage were transformed with the arcsine square root. An analysis of variance was performed and when there were statistical differences, they were subjected to a comparison of means with Tukey test ($p \leq 0.05$) using the Statistical Analysis Software (SAS Institute, 2004).

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Results and discussion

Determination of physical and chemical properties

The highest cumulative percentage of particle size from 0.24 to 0.86 mm was obtained in the biochar from sugarcane apexes (T2), with 83.37%, whereas peat moss (T1) presented the lowest distribution of this particle range (71.63%) (Table 1). On the other hand, particle sizes greater than 0.86 and up to 2.38 mm were found in T1, with 21.36%, and the lowest distribution was found in T6 (80Bsca:20P), with 12.38%. Likewise, T1 had the highest percentages of particle sizes greater than 2.38 mm (7.01%), and the lowest value was presented by T2 (3.84%).

Table 1. Granulometric distribution (percentage based on weight) in peat moss (P), biochar from sugarcane apexes (Bsca), and their mixture.

Treatment	Particle size (mm)					
	<0.24	0.24-0.86	0.86-1.15	1.15-1.68	1.68-2.38	>2.38
T1 (100P)	32.31	39.32	8.38	9.07	3.9	7.01
T2 (100Bsca)	37.92	45.45	6.21	4.7	1.87	3.84
T3 (20Bsca:80P)	29.36	43.42	8.39	8.86	3.55	6.43
T4 (40 Bsca:60P)	33.25	42.76	7.41	7.77	3.18	5.64
T5 (60 Bsca:40P)	44.61	37.02	4.58	5.69	2.84	5.27
T6 (80 Bsca:20P)	45.97	35.9	4.53	5.21	2.63	5.76

Overall, it was observed that the particle size distribution was affected by the combination of the individual materials. That is, as the percentages of biochar in the mixture increased, the cumulative percentages of particles <0.86 mm increased, whereas the distribution of particles in a range of 0.86 to 2.38 mm and >2.38 mm decreased with increasing percentages of biochar.

In contrast to these results, Pérez-Cabrera *et al*. (2021) mention that, as the percentages of rice biochar increased, the particle size of the mixture increased; this difference is due to the physicochemical composition of the original materials used in the production of biochar, which generates the decomposition of the plant material into different particle sizes.

According to the classification of Castro-Garibay *et al*. (2020), the mixtures evaluated are classified as fine since they present more than 70% of particles smaller than 0.8 mm. Likewise, these authors mention that particles <0.8 mm have a greater capacity to retain water compared to coarse particles (>0.8 mm); however, Gayosso *et al*. (2018) mention that the particle size distribution does not determine the water retention capacity in a culture medium, but that other physical characteristics that allow water containment in the substrate are also involved.

In this sense, Gutiérrez-Castorena *et al*. (2011) indicate that the movement of water in culture media depends on the intra- and inter-particle pores formed mainly by the packing, distribution, size, arrangement, and shape of the particles of a substrate or substrate mixture.

As a consequence of the arrangement and packing of the particles, the total porosity (TP) was affected by the mixing of the individual materials; this parameter decreased with increasing percentages of biochar because the size of 83.37% of its particles were composed of sizes of less than 0.86 mm. The TP of T1 (100P) and T3 (20 Bsca:80P) were statistically equal (Table 2); in contrast, T3, T4 (40 Bsca:60P), and T5 (60 Bsca:40P) did not show statistical differences between them ($p \leq 0.05$).

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Table 2. Physical properties of peat moss (P), biochar from sugarcane apexes (Bsca), and their mixture.

Treatment	TP (%)	AP (%)	MRP (%)	BD (g cm^{-3})
T1 (100P)	88.47 a	12.61 ab	75.86 a	0.12 c
T2 (100Bsca)	67.07 c	8.97 ab	58.1 c	0.15 a
T3 (20Bsca:80P)	82.16 ab	14.07 a	68.09 b	0.12 bc
T4 (40Bsca:60P)	79.87 b	12.9 ab	66.97 b	0.13 bc
T5 (60Bsca:40P)	76.83 b	7.22 b	69.61 b	0.13 b
T6 (80Bsca:20P)	65.2 c	6.65 b	58.55 c	0.15 a
CV (%)	1.81	12.14	1.53	1.83

Means with equal letters in the same column are not statistically different between treatments (Tukey, 0.05). TP= total porosity; PA= porosity of aeration; MRP= moisture retention porosity; BD= bulk density; CV= coefficient of variation.

The lowest values of TP occurred in the treatments with 100 and 80% biochar (T2 and T6), with 67.07 and 65.2%, respectively. The same trend was reported by Webber et al. (2017) in sugarcane bagasse ash mixed with peat moss (Sun Gro Horticulture), where the pore space ranged from 64.56 to 59.98% when increasing from 25% to 75% the proportion of sugarcane bagasse ash.

However, Webber et al. (2018) reported that the mixture of 25:75% biochar from sugarcane bagasse and peat moss (Sun Gro Horticulture) presented 5.61% more pore space than 100% commercial peat, with 71.18%. In this regard, Escalante-Rebolledo et al. (2016) indicate that the raw material and thermochemical techniques used in the production of biochar determine its physical and chemical characteristics.

In aeration porosity, T1, T2, T3, and T4 did not show significant differences ($p \leq 0.05$); however, the T3 treatment was significantly different ($p \leq 0.05$) from the T5 and T6 treatments, which presented the lowest percentages of aeration porosity (7.22 and 6.65%, respectively). On the

other hand, the moisture retention porosity (MRP) of T1 was significantly different ($p \leq 0.05$) from the rest of the mixtures.

These results were similar to those reported by Villegas-Torres et al. (2017), who report that the commercial mixture Sunshine3 presented a TP of 84.11%, AP of 14.59%, MRC of 69.53%, and BD of 0.11 g cm-3. Also, Mixquititla-Casbis et al. (2022) found that peat moss presented the highest values in TP, AP, and WRC, with 77.53, 18.21, and 59.32%, respectively. On the other hand, the T3 and T4 mixtures met the parameters of an ideal substrate by presenting above 70% of TP, more than 10% of aeration porosity, and moisture retention of more than 55% (Castro-Garibay et al., 2020; Mixquititla-Casbis et al., 2022).

In the biochar mixtures, total porosity, aeration porosity, and moisture retention porosity decreased with increasing biochar percentage, this may be due to the particle size distribution of the treatments presented in Table 1, which generated a decrease in pore space due to particle size (Gayosso-Rodríguez et al., 2018a).

Similar results were reported by Webber et al. (2017), who mention that the physical properties, such as pore space, water saturation, and field capacity, of sugarcane bagasse ash mixtures decreased as the percentages of biochar in the mixture increased.

The bulk density (BD) showed significant differences ($p \leq 0.05$) between treatments, this variable increased as the biochar content in the mixture increased. In relation to this, the T1 and T3 mixtures had a BD of 0.12 g cm-3, whereas T2 and T6 presented the highest values with 0.15 g cm-3. Similar results were reported by Webber et al. (2017), by mixing peat moss with sugarcane bagasse ash, BD increased as biochar percentages also increased; conversely, Webber et al. (2018) reported a BD of 0.11 g cm-3 in peat moss and when mixed with sugarcane bagasse biochar, the BD decreased.

In this regard, Barbaro (2023) indicates that the bulk density should be less than 0.4 g cm-3 to facilitate the mixing of the substrates; in addition, a low BD facilitates the loading and transfer of the containers to their final place. The bulk density of biochar shows that there is more solid material that leaves less pore space for air and water. In relation to nutritional concentration, there were differences ($p \leq 0.05$) in the elements N, P, K, Mg, and Na (Table 3).

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Table 3. Nutrient concentration of peat moss and biochar from sugarcane apexes.

Treatment	N	P	K	Ca	Mg	Na
	(mg kg^{-1})					
Peat moss	7 513.3 b	2 166.8 b	6 085.9 a	3 549.1 a	23 917 a	1 022.2 a
Biochar	2 5316.7 a	2 687.7 a	1 564.1 b	2 218.4 a	7 069 b	368.9 b
CV (%)	10.4	4.1	14.9	23.1	9	21.2

Means with equal letters in the same column are not statistically different between treatments (Tukey, 0.05). CV= coefficient of variation.

The highest concentration of N and P was found in the biochar from sugarcane apexes, with 25 316.7 and 2 687.7 mg kg^{-1}, respectively, these values represent 236.9% of N and 24% of P more than in peat moss; nevertheless, the contents of K, Mg, and Na was higher in peat moss, which, in percentage terms, mean increases of 289.1, 238.3 and 177.1%, respectively.

For the Ca element, there were no differences ($p \leq 0.05$). The high values in the nutritional concentration of peat moss may be due to the fact that it contains agricultural dolomite that confers calcium and magnesium, as reported by Calva and Espinoza (2017). However, the nutrient concentration of biochar from sugarcane apexes was higher than that reported by Velázquez-Maldonado *et al*. (2019), who, in rice husk biochar, found from 3 133 to 4 467 mg kg^{-1} of N, from 215 to 849 mg kg^{-1} of P, from 327 to 1 117 mg kg^{-1} of K, and from 554 to 1 447 mg kg^{-1} of Mg, except for Ca, whose concentration was higher than that found in the present research.

Evaluation of mixtures of biochar and peat moss in greenhouse

Commercial peat moss was the best growing medium for cucumber seedlings in stem length, fresh weight of aerial biomass, leaf area, and dry weight of aerial biomass (Table 4). In contrast, Webber *et al*. (2018) reported greater height and fresh and dry weight in squash seedlings (*Cucurbita pepo* var. Enterprise) and melon seedlings (*Cucumis melo* var. Magnum 45) with 25 and 50% mixtures of biochar from sugarcane bagasse and peat moss, and concluded that the above-mentioned ratios are excellent for the production of cucurbit seedlings without reducing production.

Table 4. Effect of mixtures of peat moss (P) and biochar from sugarcane apexes (BSCA) on the growth of cucumber seedlings.

Treatment	SL (cm)	FWAB (mg)	FWRB (mg)	LA (cm^2)	DWAB (mg)	DWRB (mg)
T1 (100P)	3.13 a	1043.5 a	722 a	11.59 a	206 a	46.67 a
T2 (100Bsca)	1.28 d	240.83 e	151 d	2.91 d	31.5 e	13.5 d
T3 (20Bsca:80P)	2.27 b	592.67 b	607.83 ab	6.02 b	104.67 b	39.83 a
T4 (40Bsca:60P)	2.1 b	547.83 bc	664.83 a	5.57 bc	96.5 b	37.33 ab
T5 (60Bsaca:40P)	1.63 c	429.5 cd	417.5 bc	4.48 c	72 c	27.67 bc
T6 (80Bsca:20P)	1.55 c	337.17 d	286.33 c	2.86 d	52.17 d	20 cd
CV (%)	10.31	1.27	2.1	5.18	1.59	19.32

Means with equal letters in the same column are not statistically different between treatments (Tukey, 0.05). SL= stem length; FWAB= fresh weight of aerial biomass; FWRB= fresh weight of root biomass; LA= leaf area; DWAB= dry weight of aerial biomass; DWRB= dry weight of root biomass; CV= coefficient of variation.

Webber *et al*. (2017) evaluated mixtures of sugarcane bagasse ash and peat moss for the cultivation of bean seedlings and found greater stem length in plants grown in 100% ash and with the 25/75

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mixture, whereas the highest total fresh and dry weight of the seedling was found with the 25/75 mixture. These same authors found that, in kale seedlings, the highest leaf length and total fresh and dry weight of the seedling was reported with the 25/75 mixture.

T3 and T4 mixtures were the best growing mediums for cucumber seedlings, after peat moss. The T3 and T4 treatments recorded taller seedlings, more fresh weight of aerial and root biomass, more leaf area, and more dry weight of aerial and root biomass compared to the T5, T6, and T2 treatments. These results can be attributed to the physical properties of the substrates, where particle size determines pore space and consequently moisture retention.

Although the seedlings produced in the T3 and T4 treatments were not the ones with the highest aerial growth, the fresh root weight was equal ($p\leq$ 0.05) to that of T1 (722 mg) as they obtained values similar to the control, with 607.83 and 664.83 mg, respectively. Likewise, no differences were found in root dry weight ($p\leq$ 0.05) between T1, T3, and T4, with values of 46.67, 39.83, and 37.33 mg, respectively. In this regard, Araméndis-Tatis *et al*. (2013) mention that the physical and chemical properties of substrates, such as aeration, water content, and nutrient availability, influence root growth.

In this sense, Montaño-Mata *et al*. (2018) mention that producers prefer seedlings with a developed root system to prevent the substrate from losing its structure when removing the seedlings from the germination tray and thus facilitate transplanting. Likewise, Cuesta and Mondaca (2014) indicate that seedling producers seek good root development and a relatively underdeveloped aboveground biomass to avoid dehydration and lodging at the time of transplantation.

Conclusions

Biochar from sugarcane apexes can be added up to 40% to commercial peat moss without altering the parameters for a substrate that is ideal in total porosity, aeration porosity, moisture retention porosity, and bulk density; also, mixtures of 20 and 40% biochar and peat moss allow the growth of cucumber seedling roots similar to those obtained in commercial peat moss.

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